Enhancing Decentralised Recycling Solutions with Digital Technologies

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ENHANCING DECENTRALISED RECYCLING SOLUTIONS WITH DIGITAL TECHNOLOGIES

Silifat Abimbola Okoya, Muyiwa Oyinlola, Patrick Schröder, Oluwaseun Kolade and Soroush Abolfathi

1 Introduction

Plastics are a very valuable commodity due to their attractive material properties such as strength, flexibility and light weight which makes them ideal for a range of applications including medical services, building, transportation and most importantly packaging (Baran, 2020; Narancic and O'Connor, 2019). However, poor plastic waste management and lack of robust recycling mechanisms have transformed plastics into one of the most significant threats to the environment, accounting for around 10% of general waste (Barnes et al., 2009; Hopewell et al., 2009; OECD, 2022). The use of plastics as packaging materials, which represents over a third of plastics produced, has precipitated a global expansion of plastic production. Consumers have increasingly embraced a throwaway culture by moving from reusable to single-use containers that are disposed within a year, thereby exacerbating the challenge of municipal solid waste (Jambeck et al., 2015). Discarding of packaging materials has been reported to have a substantial impact on the environment especially because a high proportion of these are shipped to landfill within a year of production (Barnes et al., 2009; Hopewell et al., 2009). This has led to what some have coined the "Plastic Age" (Thompson et al., 2009). Today, the threat has evolved into a major crisis with significant contributions to climate change and greenhouse emissions (Shen et al., 2020).

Global production of plastics has steadily increased over the past 50 years. For example, in 2016, global production of plastic was 335 million tonnes per annum (Drzyzga and Prieto, 2019). If the current trajectory continues, it is estimated to grow to 33 billion metric tonnes by 2050 (Jambeck et al., 2015; Rochman et al., 2013). This trend has become a major concern as plastic is non-biodegradable, and microplastics are permeating into the food chain and atmosphere (Wright

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and Kelly, 2017). Nonetheless, plastics remain essential products in the modern era largely due to the advancements in information technology, intelligent and smart packaging systems (Singh and Sharma, 2016). The main challenge is that plastic management has developed into a worldwide crisis as production has increased by 122-fold in 40 years (Joshi et al., 2019) with roughly 12.2 billion metric tonnes discarded as waste annually. That is approximately 3.9 billion metric tonnes of waste mishandled on land and 1.6 billion polluting the oceans (Jambeck et al., 2015; Rochman et al., 2013), especially the aquatic ecosystem (Bläsing and Amelung, 2018). The challenge is so pervasive that plastic waste has been proposed as a geological gauge for the Anthropocene era (Waters et al., 2016). Therefore, plastic has now emerged as a new planetary boundary menace (Galloway and Lewis, 2016; Rockström et al., 2009).

On average, high-income countries (HICs) create more plastic wastes per individual (Ritchie and Roser, 2018) as global solid waste generation correlates with gross national income per capita (Hoornweg et al., 2013; Wilson et al., 2015). In these countries, the deployment of advanced centralised recycling facilities makes the management of plastic waste more efficient. However, in Africa, the plastic pollution challenge is exacerbated by a lack of robust infrastructure and waste management systems (Oyinlola et al., 2018). The United Nations Environment Programme (UNEP) estimated that in 2015, Africa accounted for 24% of the world's total mismanaged plastic waste (UNEP, 2018a). The primary origins of waste in Africa are from households, open markets, formal institutions, public and commercial areas and the manufacturing companies (Kaseva and Mbuligwe, 2005). A United Nations (UN) report on municipal solid waste estimates that 99% of items purchased annually by consumers would be converted to waste approximately within the first six months (Ayeleru et al., 2020), with plastic being a significant player (Wilcox et al., 2015). Furthermore, fast-moving consumer goods have been found to dominate the plastic waste stream. For example, drinking water supply chain and sachet water have been identified as the biggest contributors to plastic waste in Africa. These have contributed to other issues such as clogged drains, breeding mosquitoes and localising floods (Williams et al., 2019).

The challenge of plastic waste management in Africa is exacerbated by growing population, varying consumer trends and increased urbanisation. For example, the complications of solid waste are further heightened by the increased rural to urban migration, bringing additional pressures on already overextended resources in the big cities (Yhdego, 1995). An important consideration in Africa is control of the entire value chain. Plastics enter the ecosystem from various entry points (Geyer et al., 2017), and waste pickers are not enough to meet the need. This is particularly difficult due to the lack of resources required to address issues associated with distance to disposal locations, street dumping and indiscriminate waste burning (Joshi et al., 2019). Scholars have compared the contemporary situation in Africa with the 1950s and 1960s, where waste management was efficient due to lower urban population and relatively adequate infrastructure (Achankeng, 2003; Adedibu and Okekunle, 1989; Henry et al., 2006; Kaseva and Mbuligwe, 2005).

In recent times, it was reported that the Covid-19 pandemic resulted in a change in consumer behaviour (Vanapalli et al., 2021). The situation was further aggravated by the temporary easing of the bans on single-use plastics which might have future consequences on transitioning to a circular economy (Vanapalli et al., 2021).

Plastic recycling is recognised as the most advanced method of sustainably dealing with the plastic pollution challenge (Hopewell et al., 2009; Zhong and Pearce, 2018). Prior to 1980, plastic recycling was insignificant, with the exception of non-fibre plastics (Geyer et al., 2017). While recycling rates have grown over the past decades, this growth has not been uniform across the world, a situation that has been described as the circularity divide (Barrie et al., 2022). For example, as of 2018, 32.5% of the 61.8 million tonnes of plastic produced in Europe was recycled (Plastics Europe, 2018). This compared to less than 10% in Africa (UNEP, 2018b). Despite this increase in recycling rates, the quantity of recycled plastics remains very low, and there has been continuous efforts by governments and municipalities across the world to push positive consumer recycling behaviour. Hornik et al. (1995) categorised consumer recycling behaviour into four generic groups: Firstly, intrinsic incentives such as interest in recycling determine consumers' attitudes to recycling. Secondly, extrinsic incentives such as rewards consumers receive for participating in recycling schemes are important. Thirdly, they noted that internal facilitators such as knowledge of the importance of recycling as well as the awareness of recycling programmes drive consumer behaviour. Fourthly, external facilitators such as convenience of participating in recycling programmes will usually trump incentives (Hornik et al., 1995). The gross domestic product (GDP) level and waste separation structure are critical factors that impact waste sorting, at a high or low rate, by residents based on different considerations when considering recycling behaviours as a high rate is mainly achieved when socio-demographic and external conditions are uniquely combined (Wan and Wan, 2020).

The earlier concept of recycling, especially within the industrial communities, was originally likened to the sphere of morality with the belief in right or wrong (Thøgersen, 1996). Several explanations have been postulated for the low recycling rates in low- and middle-income countries; for example, Kolade et al. (2022b) suggested that environmental concerns are usually not a priority as the majority of the population is still struggling to meet the necessities of life, such as food and shelter. Furthermore, it has been widely reported that plastic recycling is not always economically viable especially in Africa (Kreiger et al., 2014; Santander et al., 2020) as the costs of virgin plastics are usually cheaper than recycled plastics. Multinationals across Africa, such as Nestle, Coca-Cola and Pepsi, launched the "African Plastics Recycling Alliance" in 2019 (Break Free From Plastic, 2019). These corporations are among the biggest producers and distributors of fast-moving consumer goods with plastic packaging. This alliance aimed to address the end of life of the plastic value chain by improving the plastics recycling infrastructure across sub-Saharan Africa (IISD, 2019).

2 Plastic Recycling in Africa

In the Global West, recycling is usually done through centralised networks which leverage economies of scale associated with recycling of low-value products (Kreiger et al., 2014; Santander et al., 2020). This centralised approach involves the cost of transportation of high-volume and low-weight polymers (Kreiger et al., 2014; Santander et al., 2020). It can have significant environmental pollution impacts (Ragaert et al., 2017) due to the greenhouse gas emissions associated with collection and transportation (Garmulewicz et al., 2016). Although there is limited research on the comparative merits of centralised, clustered and decentralised waste management technologies, Anwar et al. (2018) noted that centralised systems realise more net profit in comparison to the decentralised and clustered methods. In practice, the approach adopted varies based on available infrastructure (Oyinlola et al., 2023b). On a large scale, plastic waste management necessitates the development of technology infrastructures. This is required at both the national and local levels in Africa guided by economic and political ability (Schroeder et al., 2023; Wilson et al., 2013). Due to resource constraints, there is a growing interest in locally managed decentralised circular economy (LMDCE) (Joshi and Seay, 2020), to allow sustainable recycling solutions which enable communities to take ownership and control of their waste. These decentralised solutions are driven by Industry 4.0 technologies such as three-dimensional (3D) printing, which upends the economies of scale, in favour of the economy of one associated with production of customised products using plastic waste as raw materials (Kolade et al., 2022a). In developing local technologies for decentralised plastic recycling, considerations need to be in place to ensure the suggested solutions are low cost, economically feasible, environment-friendly and socially suitable for it to be successful in Africa (Joshi et al., 2019). An example is the use of locally found plastic waste which was converted to plastic-derived fuel oil (PDFO) in Uganda (Joshi et al., 2019; Joshi and Seay, 2020; Schumacher, 2011). It is limited to polyolefin plastics, and although not a global solution to the plastic challenge, it is an example of a low-cost solution that can be implemented with a finite technology infrastructure (Browning et al., 2021).

Currently, there are only 67 plastic recycling plants registered in the African plastic recycling plant directory, with South Africa (22) and Nigeria (11) hosting about half of these (ENF, 2022). There might be many more unregistered recycling facilities across the continent. Furthermore, many recycling activities are semi-informal, characterised by suboptimal equipment and technologies. This wide gap in recycling facilities has fostered the creation of several small-scale enterprises aimed at tackling the challenge by using plastic waste as an economic resource (Oyinlola et al., 2022). These small and medium enterprises (SMEs) have attracted a growing support in the waste management value chain as it creates opportunities for collaboration to support a social, economic and environmental challenge. These organisations have increasingly received support from key actors such as local and foreign governments, investors, donor organisations and multinational companies, among others. They are also partnering with other actors in the value chains – e.g., the collection and disposal sector and recyclers – to facilitate sustainable waste management of plastics (Lane, 2018).

Decentralised models are gaining traction and are being adopted across Africa, especially by small-scale enterprises embracing the use of technology in waste management. The Ugandan approach to waste management was changed upon the acknowledgement that the country lacked the ability to operate a centralised operation to cater for the environmental and community requirements. A decentralised policy was therefore enacted in 1997 and further developed by the Local Government Act (Okot-Okumu and Nyenje, 2011). In addition, some countries in East Africa have transitioned from predominantly centralised models to a combination of public and private approaches with the inclusion of various stakeholders, principally service providers covering the diverse urban locations (Okot-Okumu, 2012).

A LMDCE gives waste plastic an economic value, which incentivises people to collect and use it locally, reducing waste accumulation (Babaremu et al., 2022; Oyinlola and Whitehead, 2020). It ensures the collection, disposal, remanufacture and reuse of plastics are done within the community (Joshi et al., 2019). It further significantly reduces the need for physical and technical infrastructure to implement an industrial circular economy of plastic by involving local community participation. For example, most economically disadvantaged countries have an informal local recycling ecosystem via an organisation of waste pickers (Fergutz et al., 2011; Medina, 2008; Parker, 2018). Waste pickers navigate through rural and urban cities to collect recyclable materials such as metals, plastics, glass and paper from various households and drop-off points while paying a small fee as incentive, before cleaning and sorting to further resell for a profit (Joshi et al., 2019). This process allows dense and heavily populated communities the opportunity to benefit from a decentralised circular economy, which includes plastic recycling. The circulation of plastics facilitates the replacement of the produce–consume–discard model as it develops a manufacturing supply chain by promoting using, recycling or re-entering on an industrial scale (Kaur et al., 2018; Kirchherr et al., 2017).

2.1 Overview of Digital Technologies for Waste Recycling in Africa

As highlighted previously, several small-scale enterprises have sprung up across the continent who are using digital technology such as mobile applications, geographic information systems (GIS) and artificial intelligence (AI). Oyinlola et al. (2022)

presented a summary of some of these organisations highlighting what digital technologies they use. It was observed that the common model adopted by these emerging enterprises includes at least one of the following components:

- Subscription: Majority of these start-ups have a database which is populated when customers within local communities sign up. Analysing the data gathered from these companies shows that these community-level subscriptions are usually regular, but in some cases, the interactions can be one-off. The level of interactions between the companies and subscribers is largely a function of the design of the communication campaigns, the incentives for participation and engagement and outreach activities designed by the companies. Typical customers include household, businesses, waste pickers and waste collectors. This database keeps information that allows the organisation to deliver its services, such as providing incentives, scheduling waste pickups and charging customers. Some of the start-ups (e.g., GIVO) are using their subscriptions to provide a mailing list and initiate a two-way communication with their end-users to have a better understanding of how to improve performance and services or run consumer behaviour surveys and collect market research data.
- Collection: This involves collecting recyclable waste from waste producers (including downstream users and corporate partners). Collection is done by various means including scavengers, bicycles, tricycles and mini electric vans. The quantity and type of recyclable waste collected from each collector are measured and recorded to enable incentives to be properly calculated. In recent years, new technology-based companies have adopted global positioning system (GPS) technology to track collection journeys with the aim of operational optimisation and gaining quantitative data on plastic feedstock across different communities.
- Processing: The recyclable plastics collected are sorted based on the type of plastic [polyethylene terephthalate (PET), high-density polyethylene (HDPE), polyvinyl chloride (PVC), etc.]. Depending on the feedstock condition, some of the recycling operations take the plastics through a washing and cleaning process. However, most of the decentralised plastic waste management systems try to avoid the cleaning and washing process by engaging with their communities and informing them about the feedstock quality suitable for their operations. The important stage for the mechanical recycling of the plastic is the shredding which converts the plastic waste into higher value products. The survey of the companies studied here shows that shredding can be problematic in the context of decentralised plastic waste recycling in sub-Saharan Africa. The main issue is the high cost associated with the operation and maintenance of the shredders and the scarcity of technical capacity to conduct the regular checks and services. Lack of appropriate training for staff prior to processing operations often results in overuse and overloading of mechanical equipment which often increase the maintenance need and operation costs for these businesses. Following the shredding, the recyclates will be sold to uptakers who recycle plastics.

3 Discussion

This decentralised plastic recycling approach adopted by the young tech-based entrepreneurs in sub-Saharan Africa is leading to wider societal impacts, as they mostly employ a community franchise model owned and operated by marginalised communities within the society, including women and youth in leadership positions. This approach to decentralised plastic recycling solution can be enhanced by the principle of a locally operated decentralised economy. The principle ensures suitable technology is applied to use available raw materials to manufacture goods based on accessible resources which would in turn ease the issue of unmanaged and mismanaged plastics (Browning et al., 2021). In the case of managing plastic waste, this translates to adding value to the processed recyclables by converting them into useful products. Decentralised solutions also aid efficiency and improve living of inhabitants due to localisation of processes in both rural and urban communities. These benefits can be observed in other sectors such as the energy sector with the use of decentralised hybrid photovoltaic (PV) solar-diesel power systems (Adaramola et al., 2014), the decentralised renewable energy systems (Oyedepo et al., 2018) and the health sector with decentralised health systems (Abimbola et al., 2015). Decentralised solutions have led to improved service delivery, democracy and participation and reduction in the central government's expenditure (Khan Mohmand and Loureiro, 2017).

Even though most of these organisations are embracing technology in plastic waste management, there is still significant scope to utilise technologies that deliver innovation across all aspects of the plastic value chain. For example, Chidepatil et al. (2020) suggested that AI drawing on multiple sensors and backed by the traceability of blockchain could remove barriers to a circular plastic economy. They argue that the use of AI can segregate plastic waste, therefore ensuring efficient and intelligent segregation, which is currently an inefficient process. They further argued that blockchain technology would be a useful platform for a trusted exchange across the value chain as it allows the information to be easily exchanged and validated along the value chain, providing different partners with relevant information on plastic waste and how best to reduce or recycle it. Singh (2019) illustrated how municipal waste management can make use of GIS and the layers available from remote sensing, while Mdukaza et al. (2018) highlighted the use of Internet of things (IoT) in plastic waste management. Other scholars including Hoosain et al. (2020), Kristoffersen et al. (2020) and Schot and Kanger (2018) have provided insights on how technology could be used to enhance waste management. Oyinlola et al. (2022) and Kolade et al. (2022b) have identified ten different technologies that could accelerate the transition to a circular plastic economy. Table 13.1 presents some of these technologies and highlights how they could enhance the productivity of these organisations.

TABLE 13.1 Digital technologies for the circular plastic economy

Digital Technologies	*Functionality*	*Benefits*
AI	Identification of plastic waste	Optimise circularity across the entire circular plastic economy (CPE) ecosystem
GIS	Geolocation of waste and connecting collectors to aggregators	Streamline operations in the CPE as well as efficiently connect CPE stakeholders
Blockchain	Capture of the lifecycle/journey of a plastic production	Foster transparency and facilitate data exchange across the CPE
IoT	- Waste identification and reporting to a central database via smart bins - Automated data collection from sensors - Conversion of recycled materials to finished and semi-finished products	Support embedding sensors for information exchange across the CPE
Robotics	Assisted waste sorting	Support automation across the CPE
3D printing	Repurposing plastic waste for filament production	Support decentralised recycling and reuse in the CPE
Function as a service (FaaS)	- Scalable solutions deployment - Pay-as-you-use model for infrastructural need - Digital innovations (DIs) focus more on their innovation rather than support systems	Eliminate the cost of infrastructural setup and deployment
Augmented reality/virtual reality (AR/VR)	Building digital solutions	Aid building digital solutions for awareness, sensitisation and training on best practices
5G	Real-time communication from collection centres and IoT sensors	Support real-time communication using IoT sensors
Mobile apps	- Data collection from source, information dissemination - Aggregation of data - Reward system implementation for collectors - Scheduling of waste pickup	Serve as an essential interface for all CPE stakeholders to interact for circularity

This shows that there is an opportunity to use a wide range of technologies to support the operations of decentralised plastic waste management enterprises. Some of these include the following:

- Mobile applications: for example, apps for collectors which can be used in conjunction with the hardware devices to manage the collection process, while customer apps would enable the customer to conveniently request pick up of their recyclables as well as view their historical deposits, impact of their deposit activities and incentives due. In summary, mobile apps are an essential interface for communicating across the value chain.
- IoT: Devices utilised for the collection and processing of recyclables can be integrated with IoT technology. This helps to digitise the entire process, facilitate mobile payments for recyclables collected and collate data that can be used to highlight waste consumption patterns. This also contributes to data for the entire process and is vital if blockchain is to be used. Examples of hardware devices that will benefit from IoT include scales, shredders, vehicles, etc.
- AI: This can be used for computer vision which can be utilised to identify the recyclables collected by colour, weight and brand. The computer vision technology tracks the recyclables from the collection point to the final recycled finished product, ensuring traceability and transparency of the waste management process.
- Cloud server: Information gathered from the IoT and AI enabled hardware devices can then be transmitted to the cloud server and processed in real time, for seamless record keeping and database management.
- Mobile payments: Facilitation of immediate, seamless mobile payments, as incentives for recyclables collected, to target users via mobile phones.

4 Conclusion

The future of technology within the plastic waste management system looks promising as it would foster greater interconnectedness between all stakeholders across the plastic value chain and traceability of materials collected and processed. This would in turn accelerate the transition to a more sustainable future. The application of technology such as the use of blockchain in data collection would help to make real change and optimise and inform the waste collection process. By collecting data at every stage of the plastic management cycle, the traceability of waste plastics from the source to the final recycled product is clearer. This provides valuable information about the waste streams which when applied to the circular economy principles can inform the processing, sale and repurposing of plastic goods to create a valuable economy for recyclables in Africa. Adopting digital technologies would reduce the reliance on people which could be seen as problematic in terms of jobs; however, there is an opportunity to upskill personnel in this space especially because a major challenge is the local procurement and maintenance of essential equipment such as eco-friendly and low-cost grinders and shredders with low-carbon footprints. These devices are usually sourced abroad and become obsolete once they develop a fault as there is limited local knowledge to fix them, and it is too expensive to send back to the originating country for repairs. Therefore, upskilling the current workforce to locally fabricate and maintain equipment will provide a low-cost solution that can be easily maintained over an extended period of time. It also empowers local artisans and fabricators, thereby leaving a positive footprint on the local economies of host communities.

In conclusion, decentralised plastic waste management solutions offer significant social, economic and environmental benefits to key stakeholders within the value chain. To accelerate the transition to a circular plastic economy, technological solutions need to be more modular, self-sustaining and efficient. These are necessary for effective management of the growing menace of plastic waste fuelled by linear plastic consumption culture, inadequate waste management infrastructure and unsustainable packaging activities of manufacturing and servicing organisations. Decentralised plastic waste management therefore needs to be underpinned by local sensitisation and public awareness about digital technologies for localised recycling across communities.

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